

Review Article

Impact of Resistance Circuit Training on Neuromuscular, Cardiorespiratory and Body Composition Adaptations in the Elderly

Salvador Romero-Arenas^{1, 2*}, Miryam Martínez-Pascual³ and Pedro E. Alcaraz^{1, 2}

¹Departamento de Ciencias de la Actividad Física y del Deporte, Facultad de Ciencias de la Actividad Física y del Deporte - UCAM, Universidad Católica San Antonio de Murcia, Spain.

²UCAM Research Center for High Performance Sport - UCAM, Universidad Católica San Antonio de Murcia, Spain.

³Servicio de Cardiología, Hospital General Universitario Santa Lucía, Cartagena, Murcia, Spain.

[Received June 17, 2013; Revised July 4, 2013; Accepted July 5, 2013]

ABSTRACT: Declines in maximal aerobic power and skeletal muscle force production with advancing age are examples of functional declines with aging, which can severely limit physical performance and independence, and are negatively correlated with all cause mortality. It is well known that both endurance exercise and resistance training can substantially improve physical fitness and health-related factors in older individuals. Circuit-based resistance training, where loads are lifted with minimal rest, may be a very effective strategy for increasing oxygen consumption, pulmonary ventilation, strength, and functional capacity while improving body composition. In addition, circuit training is a time-efficient exercise modality that can elicit demonstrable improvements in health and physical fitness. Hence, it seems reasonable to identify the most effective combination of intensity, volume, work to rest ratio, weekly frequency and exercise sequence to promote neuromuscular, cardiorespiratory and body composition adaptations in the elderly. Thus, the purpose of this review was to summarize and update knowledge about the effects of circuit weight training in older adults and elderly population, as a starting point for developing future interventions that maintain a higher quality of life in people throughout their lifetime.

Key words: strength training, physical training, older, body composition

Aging is defined as gradual irreversible changes in structure and function of an organism that occur as a result of the passage of time. These age-related changes affect a broad range of tissues, organ systems and functions which, cumulatively, can negatively impact activities of daily living in older adults [1]. The identification of pharmacological, surgical and exercise interventions that can minimize or reverse the age-related physiological decline is of primary importance. Because of the known problems with pharmacological [2-4] and exercise-related [5] program adherence in older individuals, a successful intervention has to be both time

and (monetary) cost efficient. Given that pharmacological and surgical interventions have very specific effects on physiological functions, exercise represents the most likely single intervention that can achieve a broad range of physiological changes. Nonetheless, adaptations are specific to the exercise mode and intensity, so several concurrently implemented regimes need to be performed.

The American College of Sports Medicine (ACSM) Position Stand "Exercise and Physical Activity for Older Adults" highlight that the pillars of an exercise program for older adults should be two exercise modalities: 1)

*Correspondence should be addressed to: Prof. Salvador Romero-Arenas, Facultad de las Ciencias de la Actividad Física y del Deporte, Universidad Católica San Antonio de Murcia, Murcia, SPAIN. Email: sromero@ucam.edu

aerobic exercise and 2) resistance exercise [1]. It is well known that both endurance exercise and resistance training can substantially improve physical fitness and health-related factors in older individuals [6-8]. However, while endurance training is purported to be more effective for decreasing fat mass [9], resting heart rate [10] and blood pressure [11], resistance training has been shown to be more effective for increasing basal metabolism [12, 13], bone mineral density (BMD) [14-17], muscle strength and power [18-20], and muscle and connective tissue cross-sectional area [21]. Thus, whilst an exercise program incorporating both aerobic and resistance exercises can result in significant and wide-ranging improvements in body composition and physiological function, the time and monetary investment may be problematic for program adherence.

Circuit weight training (CWT) is an exercise modality thought to stimulate systems that promote both cardiovascular and strength benefits. Such programs consist of series, usually 10-15, of resistance exercises for different body parts. For each exercise 12-15 repetitions, using modest weights (approximately 40-60% of one repetition maximum (RM)), are performed. Each exercise is typically completed within 30-40 s. The participant moves quickly from one exercise to the next with 15-30 s of rest between stations. The circuit is repeated one to three times depending on fitness level. Thus, it takes about 30 min to complete an exercise session [22]. Some researchers have shown that circuit-based resistance training, is very effective for increasing maximum oxygen consumption, maximum pulmonary ventilation, functional capacity, and strength while improving body composition [23-26]. Thus, circuit training a time-efficient training modality that can elicit demonstrable improvements in health and physical fitness. Unfortunately, the increase in muscular strength and mass in response to conventional CWT are modest. However, new evidence and exercise strategies have indicated that high-intensity (6RM) may influence the magnitude of neuromuscular and cardiovascular adaptations in elderly [6]. One recent research has also suggested that high-resistance circuit training produce strength, muscle mass and bone mineral density gains in healthy older population. These improvements were similar to those obtained with traditional heavy-resistance training, with the advantage that high-resistance circuit training requires less time than traditional strength training. In addition, only high-resistance circuit training elicited greater adaptations in cardiovascular system and body composition (i.e. decrease fat mass) [17].

To optimize the circuit weight training prescription, it seems reasonable to identify the most effective combination of intensity, volume, work to rest ratio,

weekly frequency and exercise sequence to promote neuromuscular, cardiorespiratory and body composition adaptations in the elderly. Therefore, the aim of this review was to summarize and update knowledge about the effects of circuit weight training in older adults and elderly people, as a starting point for developing future interventions that maintain a higher quality of life in people throughout their lifetime.

What effect does circuit weight training have on body composition and bone mineral density?

Muscle mass loss is one of the most evident facts of aging, not only for its aesthetic repercussion, but also for the functional modifications that it entails in the organism. Many of these functional modifications are related to health. From the metabolic point of view, the most important consequence of sarcopenia is the decrease in energy expenditure and basal metabolic decline. Furthermore, sarcopenia causes loss of strength and mobility, and hence, physical disability. The decreased energy expenditure and ingestion of diets with the same calorie content than in previous ages, causes the increase in body weight and fat mass. They both facilitate the onset of diabetes and worsening of high blood pressure (when it exists).

Circuit weight training has been shown to be an effective non-pharmacological method to reduce body weight and physical disability in obese older people [27]. It is known that one factor contributing to the failure of the treatment of obesity is maintaining a lower calorie diet intake for long periods, causing demotivation. An important feature of CWT is that it allows the possibility of a large number of people taking part in the same exercise session. This fact corresponds to the wide variety of exercise as well as the increased possibility of intrapersonal relationships with exercise practice, leading to higher level of motivation during training.

Fat mass

The prevalence of overweight people is a serious public health concern, and is a risk factor for developing cardiovascular and metabolic disorders. The volume, frequency, work to rest ratio and intensity of training play a fundamental role in the resistance circuit training-induced adaptations in the elderly subjects. Most studies that have shown significant reductions in body fat use a frequency of training of 2 - 3 sessions per week. Romero et al. [17] showed a decrease of 4.4% in body fat with only two sessions per week. Furthermore, this decrease was greater than the one produced with traditional resistance training, using the same volume (1 to 3 sets) and the same intensity (6RM, \approx 85% of 1RM) of

training. The only difference was the smallest rest interval between exercises during the resistance circuit training (35 s vs. 3 min).

The rest of the available studies used a frequency of training of three sessions per week. Bocalini et al. [27] studied the effect of circuit training (50 min approximately) with a work to rest ratio of 1:1 (45: 40 s) and low intensity (as they used exercises with elastic bands). This authors observed that depending on the initial state of subjects, training affected in a different way, thus, the body fat reduction was 4.6%, 11% and 21.4% for participants with normal weight, overweight and obesity, respectively. Takeshima et al. [28], after 12 weeks of training (30 min per session), with a work to rest ratio of 1:1 (30:30 s) and a moderate intensity of training, observed a 16% decrease in body fat. This decrease is higher than the one in other studies that assess the effect of resistance circuit training on body fat. This can be due to that the exercise circuit consisted of 30 s of resistance exercise interspersed with 30 s of "aerobic-dance" movements (70% of heart rate reserve), which the participants marching in place and raising the arms for 30 s.

Using similar volumes and frequency for circuit low-intensity and circuit high-intensity groups, Paoli et al. [6] found greater decrease in body fat in the group that used a high intensity. It was probably due to the greater EPOC (excess post exercise oxygen consumption) in the hours following exercise. This increase of EPOC may explain the greater reduction of fat in the circuit group. This findings are similar to those of others authors that showed that higher intensity session produced higher EPOC than standard set exercise (12-15 repetitions) [29], moreover there are data demonstrating that repeated bouts of aerobic exercise can activate more effectively adipose tissue lipolysis than conventional aerobic training.

Lean mass

Despite the importance of maintaining muscle mass in the elderly, there are not many studies that have investigated the morphological adaptations after circuit weight training. Aging often leads to a loss of functional fitness in older people, reducing their ability to perform daily tasks. Moreover, fall-related injuries are serious problems in old age, as they often lead to prolonged, or even permanent, disability. Therefore, maintenance of lean mass is frequently considered an important strategy for improving functional fitness, preventing body weight gain, reducing disability, improving the quality of life, and reducing the cost of health care.

In the study of Romero-Arenas et al. [17], it was found that improvement in lean mass in response to

high-resistance circuit training were similar to those obtained by traditional heavy-resistance training. In this research, participants performed 1-3 sets of exercise twice a week with high intensity (6RM). A significant drawback of standard circuit training programs, however, is that the loads lifted are typically low, so the stimulus for muscle mass adaptations is minimal.

Bone Mass

Osteoporosis is a disease characterized by low bone mass and deterioration of bone tissue. This leads to increased bone fragility and risk of fracture (broken bones), particularly of the hip, spine, wrist and shoulder. Osteoporosis is often known as "the silent thief" because bone loss occurs without symptoms. It is well known that the risk of fractures is closely related to the decline in bone mass during the aging process, in both women and men [30]. Moreover, net bone loss is also accelerated with age. Although it is known that an increase in levels of physical activity may lead to enhance bone mass, it is suggested that the best way to improve all bone-related variables is to include specific exercise training programs.

Several training methods have been used to improve bone mineral content and bone mineral density in prospective studies. However, not all forms of exercise have the same positive effects on bone mass and because of that the studies that evaluated the role of exercise programs on bone-related variables in elderly people have obtained conflicting results [16]. Strength training is one of the most frequent types of exercise programs applied in order to improve bone mass in elderly people. The increased mechanical stress on the bone provided by this type of training has been demonstrated as a causal factor of osteogenesis [31].

A significant drawback of standard circuit training programs is that the loads lifted are typically low, so the stimulus for bone mass adaptations is minimal. The low intensities normally adopted in traditional circuit weight training may limit the possibility of increasing BMD [23]. Thus, the few studies [14, 23] that have examined the effects of resistance circuit training on BMD in older people found no change, suggesting that the higher loading intensity was key to stimulating increases in BMD. Recently, Romero-Arenas et al. [17] found that a high-resistance circuit training resulted in significant increases in BMD. After 12 weeks of training, with high-load (6RM), whole body BMD was moderately and uniformly increased (1.2%), whereas it did not change (-0.3%) in the control group. These results showed that bone mass can be significantly increased by a strength regimen with high-load low repetitions but not by an endurance regimen with low-load high repetitions.

Therefore, the peak load seems to be more important than the number of repetitions (always over a threshold) in increasing bone mass [16].

What effect does circuit weight training have on muscle strength?

Recent studies showed that muscle strength is a good predictor of mobility and disability in older adults [32]. Everyday tasks are motor acts performed during a day that contribute to physical independence, such as rising from seated position, ascending or descending stairs, walking and taking a shower. Challenges encountered during daily activities, which are easily overcome by young adults, may represent a potential risk for falls among the elderly [33, 34]. Thus, maximum muscular strength is strongly and negatively associated with risk of all cause mortality [35, 36] and is thought to be a major factor influencing ambulatory or daily ability and fall risk in the elderly [33]. Although it is known that heavy strength training elicits substantial gains in muscular strength, even in the oldest individuals [18], circuit training using lower loads has previously been shown not to promote comparable strength increases as traditional weights training [23] in older adults. This is probably because the use of high loads in resistance training is known to be mandatory for optimum gains in muscular strength [37, 38] and is a key determinant of overall muscle fiber hypertrophy [39].

Few previous studies have examined the effect of high-resistance circuit training, probably because subjects were not considered to be able to develop the same muscular force outputs due to fatigue resulting from the short recovery time. However, Romero-Arenas et al. [17] found that the isokinetic strength gains were similar when older adults performed high-resistance circuit vs. traditional heavy-resistance training. Paoli et al. [6] subsequently examined the effects of high-resistance circuit vs. traditional (lower load) circuit training in older adults (50 – 65 years old) and found that high intensity was more effective than low intensity circuit training for improving muscle strength.

What effect does circuit weight training have on cardiovascular parameters?

The decline in capacity cardiorespiratory in the elderly is primarily associated with a decrease in the maximal heart output caused by reduction in the maximum stroke volume and heart rate and the change in the oxygen artero-venous difference [40]. Resistance training, besides producing fiber hypertrophy, causes changes in the mechanisms responsible for the transport and utilization of oxygen. These mechanisms consist of an

increase in capillary density per fiber and an increase in the oxidative capacity of the muscle cell, as reflected by an increased citrate synthase activity [41]. It has also been described modifications in the way in which muscles use energy, such as the increase in the degradation of phosphagen and glycogen and a better utilization of intramuscular triglycerides. It is possible that all these changes may explain the improvements in oxygen consumption in people who perform resistance circuit training, including older adults.

Studies that have investigated cardiovascular adaptations to circuit weight training have shown increases from 15% to 18,6% in VO_{2max} , using a program with 8 – 12 stations implemented three days per week [23, 28]. Brentano et al. [23] developed a circuit-based exercises program in postmenopausal women which produced significant improvements in VO_{2max} (18,6%) after 24 weeks of training with intensities of 40-60% of 1RM. Takeshima et al. [28] developed a Nautilus circuit training (i.e. hydraulic-resistance machine) with resistance exercises interspersed with aerobic-dance movements during 12 weeks and moderate intensity getting an increase of 15% in VO_{2max} . The rest interval length in both studies varied between no rest [23] to 30 s [28] with work intervals of 30 s. These intervals can be used as guidelines of a program for improving VO_{2max} [42]. The work to rest ratio is also a critical factor in prescribing of circuit training for the improvement of aerobic fitness (Table 1), as it can influence to adaptations and recovery. There is no a standard work to rest ratio, although work to rest ratios used more frequently are 1:1 (30:30 s) or 2:1 (30:15 s) [43]. Therefore, a short rest period during circuit weight training does appear to augment improvements in VO_{2max} .

In addition to improvements in VO_{2max} , other factors (i.e. energy efficiency) influence the performance of daily living tasks, and independence of older adults. The ability to walk efficiently and safely is important to maintain independence [44]. However, the energy cost of gait in the elderly people is high, which can cause early fatigue [45]. This is due to a change in muscle fiber type with aging and a higher percentage of peak oxygen uptake required to perform daily tasks [40, 46]. Hence, the effectiveness of a training program to improve cardiovascular health and the energy efficiency (production of adenosine triphosphate with minimal work) may help to prevent cardiovascular disease and improve movement economy in older individual. Romero-Arenas et al. [17] showed that O_2 consumption at submaximal walking intensities decreased, which is indicative of an improvement in walking economy after 12 weeks of high-resistance circuit training ($\approx 85\%$ of 1RM).

A summary of resistance circuit training guidelines is presented in Table 1.

Table 1. Summary of guidelines to prescribe circuit weight training

Exercise mode	Machines are preferred for safety and ease of use. Primarily use single-joint exercises, and progressing to multi-joint exercises.
No. of exercises	6 to 10 exercises covering the all-major muscle groups of the body.
Frequency	Circuit weight training should be done at least twice per week; and could be implemented with endurance training.
Volume	1 – 3 sets (30 – 50 min).
Intensity	Resistance (load) should begin with 18 - 20RM (40 - 60% of 1RM), and progressing to 6RM (85% of 1RM).
Work to rest ratio	1:1 (30:30 s), and progressing to 2:1 (30:15 s).
Precautions	Avoid extended breath holding and straining (Valsalva maneuver) during weight training to minimize exaggerated blood pressure response.

What effect does circuit weight training have on risk factors for age-related diseases?

The inclusion of resistance training as part of an exercise program for promoting health and preventing disease has been endorsed by the American Heart Association [47], American College of Sport Medicine [48], and the American Diabetes Association [49] as an integral part of an overall health and fitness program. Several studies have shown the beneficial effects of the performance of circuit weight training in elderly individuals with age-related diseases. Palevo et al. [50] demonstrated that, after eight weeks of circuit weight training, patients with chronic heart failure due to left ventricular systolic dysfunction increased a 16% in ejection fraction, 15% in stroke volume, and muscle strength by an average of 23%. Volaklis et al. [51] combined resistance circuit and aerobic exercise program during eight month. The program consisted of four sessions per week; two sessions involved aerobic exercise and two sessions consisted of circuit weight training. After eight month patients with coronary artery disease improved cardiovascular fitness (VO_{2peak} 15.4% and exercise time 14%), and muscular strength also increased significantly in all exercises by an average of 28%.

Safety issues such as an exaggerated increase in blood pressure, palpitations, or syncope have been a historical concern with strength training in patients with cardiovascular disease [52]. The avoidance of breath holding and straining (Valsalva maneuver) during weight training can prevent increases in blood pressure [53]. Several studies have investigated the effect of circuit weight training on blood pressure and arterial stiffness. Simões et al. [54] compared the effects of the resistance circuit at 23 and 43% of 1RM intensity on the postexercise blood pressure response in healthy subjects. They observed a higher reduction of postexercise blood pressure with an intensity of 43% of 1RM. Another study showed that there is a blood pressure reduction during the first 60 minutes after low-intensity (40% of 1RM) circuit-type resistance exercise with different volumes (1 vs. 2 sets). Only the highest volume session (2 sets) promoted a reduction of mean 24-hour blood pressure [55]. In postmenopausal women, a moderate-intensity combined resistance circuit and endurance exercise training, performed three days per week, resulted in beneficial effects on arterial stiffness and blood pressure [56].

Diabetes mellitus, glucose intolerance, and insulin resistance are central features of coronary artery disease risk. Muscle contraction increases glucose uptake in skeletal muscle [57], thereby forming the basis for recommending resistance training for individuals with abnormal glucose metabolism. In type II diabetic patients, eight weeks of moderate intensity (50-60% of 1RM) resistance circuit training was not enough to produce changes in metabolic risk factors [58]. However, resistance circuit training (60-80% of 1RM) combined with endurance exercise training (at 55-70% of VO_{2max}) improved metabolic risk factors (i.e. HbA_{1c} , reduced by 0.45%; fasting blood glucose, reduced by 21.6%; waist circumference, reduced by 3.0%; body weight, reduced by 2.1%; systolic blood pressure, reduced by 8.0%; and total cholesterol, reduced by 16.4%) [59].

Conclusion

Circuit training is a versatile training modality that allows the possibility of a large number of people taking part in the same exercise session, requiring less time than other modalities. The circuit weight training is a great strategy to improve the body composition, muscle strength and cardiovascular functions and, consequently, to maintain functional capacity during aging. In addition, patients with several diseases may improve their quality of life; thus, resistance circuit training may be included in their treatment.

Based on recent evidence, strategies have been provided to optimize the body composition, muscle

strength gains, and to develop cardiovascular function, as follow:

1) The performance of a minimum weekly frequency of circuit weight training should be 2 sessions per week, and could be implemented with endurance training.

2) Circuit weight training should be developed with a volume ranging from 30-50 min. The number of sets and the repetitions per exercise is going to depend on intensity training.

3) The loading intensity to promote hypertrophy should approach 60-85% (more highly trained individuals 85%) of 1RM, although we also recommend low intensity (e.g. 40% of 1RM), high velocity contractions on at least 1 day per week to develop muscle power.

4) The work to rest ratio is also a critical factor in prescribing of circuit training. The work to rest ratio 1:1 (30:30 s) may be an excellent stimulus to promote improvements on aerobic fitness, and modifications on body composition (i.e. decrease body fat).

Acknowledgements

The authors are indebted to the Consejo Superior de Deportes for financing this research with the grant numbered 07/UPR20/10. The authors have no conflicts of interest. No potential conflict of interest relevant to this article was reported.

References

- [1] Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, Skinner JS (2009). American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc*, 41(7): 1510-1530.
- [2] Haynes RB, Ackloo E, Sahota N, McDonald HP, Yao X (2008). Interventions for enhancing medication adherence. *Cochrane Database Syst Rev*, (2): CD000011.
- [3] Maclaughlin EJ, Raehl CL, Treadway AK, Sterling TL, Zoller DP, Bond CA (2005). Assessing medication adherence in the elderly: which tools to use in clinical practice? *Drugs & Aging*, 22(3): 231-255.
- [4] Osterberg L, Blaschke T (2005). Adherence to medication. *N Engl J Med*, 353(5): 487-497.
- [5] Karen A, Schutzer RN (2004). Barriers and motivations to exercise in older adults. *Preventive Medicine*, 39(5): 1056-1061.
- [6] Paoli A, Pacelli F, Bargossi AM, Marcolin G, Guzzinati S, Neri M, Bianco A, Palma A (2010). Effects of three distinct protocols of fitness training on body composition, strength and blood lactate. *J Sports Med Phys Fitness*, 50(1): 43-51.
- [7] Cadore EL, Izquierdo M, Alberton CL, Pinto RS, Conceicao M, Cunha G, Radaelli R, Bottaro M, Trindade GT, Kruel LF (2012). Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Exp Gerontol*, 47(2): 164-169.
- [8] Cadore EL, Izquierdo M, Pinto SS, Alberton CL, Pinto RS, Baroni BM, Vaz MA, Lanferdini FJ, Radaelli R, Gonzalez-Izal M, Bottaro M, Kruel LF (2013). Neuromuscular adaptations to concurrent training in the elderly: effects of intrasession exercise sequence. *Age (Dordr)*, 35(3): 891-903.
- [9] Kay SJ, Fiatarone Singh MA (2006). The influence of physical activity on abdominal fat: a systematic review of the literature. *Obes Rev*, 7(2): 183-200.
- [10] Huang G, Shi X, Davis-Breznitz JA, Osness WH (2005). Resting heart rate changes after endurance training in older adults: a meta-analysis. *Med Sci Sports Exerc*, 37(8): 1381-1386.
- [11] Seals DR, Hagberg JM, Hurley BF, Ehsani AA, Holloszy JO (1984). Endurance training in older men and women. I. Cardiovascular responses to exercise. *J Appl Physiol*, 57(4): 1024-1029.
- [12] Hunter GR, Wetzstein CJ, Fields DA, Brown A, Bamman MM (2000). Resistance training increases total energy expenditure and free-living physical activity in older adults. *J Appl Physiol*, 89(3): 977-984.
- [13] Paoli A, Moro T, Marcolin G, Neri M, Bianco A, Palma A, Grimaldi K (2012). High-Intensity Interval Resistance Training (HIRT) influences resting energy expenditure and respiratory ratio in non-dieting individuals. *Journal of translational medicine*, 10(1): 237.
- [14] Rhodes EC, Martin AD, Taunton JE, Donnelly M, Warren J, Elliot J (2000). Effects of one year of resistance training on the relation between muscular strength and bone density in elderly women. *Br J Sports Med*, 34: 18-22.
- [15] Vincent KR, Braith RW (2002). Resistance exercise and bone turnover in elderly men and women. *Med Sci Sports Exerc*, 34(1): 17-23.
- [16] Gomez-Cabello A, Ara I, Gonzalez-Aguero A, Casajus JA, Vicente-Rodriguez G (2012). Effects of training on bone mass in older adults: a systematic review. *Sports Med*, 42(4): 301-325.
- [17] Romero-Arenas S, Blazejczyk AJ, Martinez-Pascual M, Perez-Gomez J, Luque AJ, Lopez-Roman FJ, Alcaraz PE (2013). Effects of high-resistance circuit training in an elderly population. *Exp Gerontol*, 48(3): 334-340.
- [18] Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ (1990). High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA*, 263(22): 3029-3034.
- [19] Hakkinen K, Pakarinen A, Kraemer WJ, Hakkinen A, Valkeinen H, Alen M (2001). Selective muscle hypertrophy, changes in EMG and force, and serum hormones during strength training in older women. *J Appl Physiol*, 91(2): 569-580.
- [20] Lexell J, Downham DY, Larsson Y, Bruhn E, Morsing B (1995). Heavy-resistance training in older Scandinavian men and women: short- and long-term

- effects on arm and leg muscles. *Scand J Med Sci Sports*, 5(6): 329-341.
- [21] Hunter GR, McCarthy JP, Bamman MM (2004). Effects of resistance training on older adults. *Sports Med*, 34(5): 329-348.
- [22] Tesch PA (1992). Training for bodybuilding. In PV Komi, Editor *Strength and power in sport*. Blackwell Scientific Publications. p. 370-381.
- [23] Brentano MA, Cadore EL, Da Silva EM, Ambrosini AB, Coertjens M, Petkowicz R, Viero I, Kruel LF (2008). Physiological adaptations to strength and circuit training in postmenopausal women with bone loss. *J Strength Cond Res*, 22(6): 1816-1825.
- [24] Camargo MD, Stein R, Ribeiro JP, Schvartzman PR, Rizzatti MO, Schaan BD (2008). Circuit weight training and cardiac morphology: a trial with magnetic resonance imaging. *Br J Sports Med*, 42(2): 141-145.
- [25] Gettman LR, Ayres JJ, Pollock ML, Durstine JL, Grantham W (1979). Physiologic effects on adult men of circuit strength training and jogging. *Arch Phys Med Rehabil*, 60(March): 115-120.
- [26] Harber MP, Fry AC, Rubin MR, Smith JC, Weiss LW (2004). Skeletal muscle and hormonal adaptations to circuit weight training in untrained men. *Scand J Med Sci Sports*, 14(3): 176-185.
- [27] Bocalini DS, Lima LS, de Andrade S, Madureira A, Rica RL, Dos Santos RN, Serra AJ, Silva JA, Jr., Rodriguez D, Figueira A, Jr., Pontes FL, Jr. (2012). Effects of circuit-based exercise programs on the body composition of elderly obese women. *Clinical interventions in aging*, 7: 551-556.
- [28] Takeshima N, Rogers ME, Islam MM, Yamauchi T, Watanabe E, Okada A (2004). Effect of concurrent aerobic and resistance circuit exercise training on fitness in older adults. *Eur J Appl Physiol*, 93(1-2): 173-182.
- [29] Murphy E, Schwarzkopf R (1992). Effects of standard set and circuit weight training on excess post-exercise oxygen consumption. *J Appl Sport Sci Res*, 6(2): 88-91.
- [30] Nguyen ND, Pongchaiyakul C, Center JR, Eisman JA, Nguyen TV (2005). Abdominal fat and hip fracture risk in the elderly: the Dubbo Osteoporosis Epidemiology Study. *BMC musculoskeletal disorders*, 6: 11.
- [31] Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenberg RA, Evans WJ (1994). Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. A randomized controlled trial. *JAMA*, 272(24): 1909-1914.
- [32] Clark DJ, Fielding RA (2012). Neuromuscular contributions to age-related weakness. *J Gerontol A Biol Sci Med Sci*, 67(1): 41-47.
- [33] Tiedemann A, Sherrington C, Close JC, Lord SR (2011). Exercise and Sports Science Australia position statement on exercise and falls prevention in older people. *J Sci Med Sport*, 14(6): 489-495.
- [34] Cardozo AC, Gonçalves M, Hallal CZ, Marques NR (2013). Age-related neuromuscular adjustments assessed by EMG. In H Turker, Editor *Electrodiagnosis in New Frontiers of Clinical Research*. Croatia: InTech. p. 113-129.
- [35] Metter EJ, Talbot LA, Schrager M, Conwit R (2002). Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J Gerontol A Biol Sci Med Sci*, 57(10): B359-365.
- [36] Ruiz JR, Sui X, Lobelo F, Morrow JR, Jackson AW, Sjöström M, Blair SN (2008). Association between muscular strength and mortality in men: prospective cohort study. *BMJ*, 337: 92-95.
- [37] Berger RA (1962). Optimum repetitions for the development of strength. *Res Q*, 33(334-8).
- [38] Caiozzo VJ, Perrine JJ, Edgerton VR (1981). Training-induced alterations of the in vivo force-velocity relationship of human muscle. *J Appl Physiol*, 51(3): 750-754.
- [39] Fry AC (2004). The role of resistance exercise intensity on muscle fibre adaptations. *Sports Med*, 34(10): 663-679.
- [40] Astrand I, Astrand PO, Hallback I, Kilbom A (1973). Reduction in maximal oxygen uptake with age. *J Appl Physiol*, 35(5): 649-654.
- [41] Frontera WR, Meredith CN, O'Reilly KP, Evans WJ (1990). Strength training and determinants of VO₂max in older men. *J Appl Physiol*, 68(1): 329-333.
- [42] Waller M, Miller J, Hannon J (2011). Resistance circuit training: Its application for the adult population. *Strength and Conditioning Journal*, 33(1): 16-22.
- [43] Romero-Arenas S, Pérez-Gómez J, Alcaraz PE (2011). Entrenamiento en circuito. ¿Una herramienta útil para prevenir los efectos del envejecimiento? *Cultura, Ciencia y Deporte*, 6(18): 185-192.
- [44] Callisaya ML, Blizzard L, Schmidt MD, McGinley JL, Srikanth VK (2010). Ageing and gait variability--a population-based study of older people. *Age Ageing*, 39(2): 191-197.
- [45] Hortobagyi T, Solnik S, Gruber A, Rider P, Steinweg K, Helseth J, DeVita P (2009). Interaction between age and gait velocity in the amplitude and timing of antagonist muscle coactivation. *Gait & posture*, 29(4): 558-564.
- [46] Waters RL, Hislop HJ, Perry J, Thomas L, Campbell J (1983). Comparative cost of walking in young and old adults. *Journal of orthopaedic research : official publication of the Orthopaedic Research Society*, 1(1): 73-76.
- [47] Pollock ML, Franklin BA, Balady GJ, Chaitman BL, Fleg JL, Fletcher B, Limacher M, Piña IL, Stein RA, Williams M, Bazzarre T (2000). Resistance exercise in individuals with and without cardiovascular disease: benefits, rationale, safety, and prescription: An advisory from the Committee on Exercise, Rehabilitation, and Prevention, Council on Clinical Cardiology, American Heart Association; Position paper endorsed by the American College of Sports Medicine. *Circulation*, 101(7): 828-833.
- [48] Pescatello LS, Franklin BA, Fagard R, Farquhar WB, Kelley GA, Ray CA (2004). American College of Sports Medicine position stand. Exercise and hypertension. *Med Sci Sports Exerc*, 36(3): 533-553.

- [49] Sigal RJ, Kenny GP, Wasserman DH, Castaneda-Sceppa C (2004). Physical activity/exercise and type 2 diabetes. *Diabetes Care*, 27(10): 2518-2539.
- [50] Palevo G, Keteyian SJ, Kang M, Caputo JL (2009). Resistance exercise training improves heart function and physical fitness in stable patients with heart failure. *J Cardiopulm Rehabil Prev*, 29(5): 294-298.
- [51] Volaklis KA, Douda HT, Kokkinos PF, Tokmakidis SP (2006). Physiological alterations to detraining following prolonged combined strength and aerobic training in cardiac patients. *Eur J Cardiovasc Prev Rehabil*, 13(3): 375-380.
- [52] Williams MA, Haskell WL, Ades PA, Amsterdam EA, Bittner V, Franklin BA, Gulanick M, Laing ST, Stewart KJ, Cardiology AHACoC, American Heart Association Council on Nutrition PA, and Metabolism (2007). Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation*, 116(5): 572-584.
- [53] Evans WJ (1999). Exercise training guidelines for the elderly. *Med Sci Sports Exerc*, 31(1): 12-17.
- [54] Simoes GC, Moreira SR, Kushnick MR, Simoes HG, Campbell CS (2010). Postresistance exercise blood pressure reduction is influenced by exercise intensity in type-2 diabetic and nondiabetic individuals. *J Strength Cond Res*, 24(5): 1277-1284.
- [55] Scher LM, Ferriolli E, Moriguti JC, Scher R, Lima NK (2011). The effect of different volumes of acute resistance exercise on elderly individuals with treated hypertension. *J Strength Cond Res*, 25(4): 1016-1023.
- [56] Figueroa A, Park SY, Seo DY, Sanchez-Gonzalez MA, Baek YH (2011). Combined resistance and endurance exercise training improves arterial stiffness, blood pressure, and muscle strength in postmenopausal women. *Menopause*, 18(9): 980-984.
- [57] Miller JP, Pratley RE, Goldberg AP, Gordon P, Rubin M, Treuth MS, Ryan AS, Hurley BF (1994). Strength training increases insulin action in healthy 50- to 65-year-old men. *J Appl Physiol*, 77(3): 1122-1127.
- [58] Hazley L, Ingle L, Tsakirides C, Carroll S, Nagi D (2010). Impact of a short-term, moderate intensity, lower volume circuit resistance training programme on metabolic risk factors in overweight/obese type 2 diabetics. *Res Sports Med*, 18(4): 251-262.
- [59] Fatone C, Guescini M, Balducci S, Battistoni S, Settequattrini A, Pippi R, Stocchi L, Mantuano M, Stocchi V, De Feo P (2010). Two weekly sessions of combined aerobic and resistance exercise are sufficient to provide beneficial effects in subjects with Type 2 diabetes mellitus and metabolic syndrome. *J Endocrinol Invest*, 33(7): 489-495.